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Project Background

Introduction

As the federal government continues to encourage the use of alternative fuels for transportation, the U.S. Department of Energy (DOE) has established programs to advance the production and use of alternative fuel vehicles (AFVs). To support this activity, DOE directed its National Renewable Energy Laboratory (NREL) to develop and conduct projects to evaluate the performance of light-duty AFVs compared to similar gasoline vehicles. Light-duty AFVs such as passenger cars, minivans, and pickup trucks were the subjects of these studies.

For this project, NREL contracted with Transportation Research Center, Inc. (TRC) to conduct performance tests on selected light-duty AFV models. Automotive Testing Laboratories, Inc. (ATL), an independent emissions laboratory with facilities at the TRC proving grounds complex in East Liberty, Ohio, provided program support to TRC. TRC and ATL conducted a series of performance and evaluation tests, including acceleration, braking, fuel economy, driveability and handling, emissions, and cold-start tests, on the selected AFVs. Each designated AFV was evaluated in parallel with a conventional gasoline-powered vehicle of the same make and model. Fact sheets containing data from this project help fleet managers and other consumers weigh this information when considering AFV purchases.



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Vehicles

AFVs can have dedicated, bi-fuel, or flexible-fuel fuel systems. A dedicated vehicle is designed to operate on only one fuel. Dedicated AFVs currently available from the original equipment manufacturers (OEMs) include compressed natural gas (CNG) vehicles. Several vehicle design modifications are required to enable the various vehicle models to operate on a gaseous fuel. System changes vary from design to design depending on the level of optimization. These changes include replacing the fuel tank with high-pressure gas cylinders; installing a new fuel injection system; performing unique calibrations and programming the electronic control module; actuators and sensors to control the air/fuel ratio; incorporating specially designed catalytic converters and

other equipment related to fuel management, such as pressure relief devices.

Bi-fuel vehicles are equipped to carry both gasoline and natural gas or propane, fuels that require separate fuel systems. Changes to the vehicle are the same as those made on the dedicated gaseous fuel model, except that the gasoline system is not replaced. Although a switch is installed to allow the driver to change from operation on gasoline to running on the alternative fuel, most bi-fuel vehicles sold today are designed to default to operation on alternative fuel if it is available. When the pressure in the gaseous fuel tank falls below a preset value, the system automatically switches to operate on gasoline.

A flexible-fuel vehicle (FFV) can operate on any combination of the respective alternative fuel (ethanol or methanol) and gasoline, up to a blend of 85% alternative fuel and 15% gasoline. The design changes required to enable operation on alcohol fuels are less extensive than those required to accommodate operation on a gaseous fuel. However, some modifications to the conventional gasoline engine are required to avoid major problems with preignition, engine wear, and material compatibility. A fuel sensor (usually found in the fuel tank) determines the percentage of alcohol in the fuel blend. The sensor's output is used by the vehicle's computer to adjust the engine's parameters for maximum efficiency. Other modifications include alcohol-resistant materials in the fuel system and an engine microprocessor designed to compensate for varying fuel blends.

Test Configurations

The test program was designed to conduct tests on an AFV and its gasoline-powered counterpart. The AFV and its gasoline model were "matched" as closely as possible for model, model year, engine, and other major vehicle components. For each test, the vehicle pair was tested on the same day (concurrently if possible) to eliminate differences caused by weather variations.

Dedicated AFVs were paired with gasoline matches and each was run through the various tests in the plan while operating on the designated fuel.

Flexible-fuel vehicles were paired with a gasoline match (where one was available). The flexible-fuel AFV was run through the series of tests twice, once on the 85% alcohol blend and once on 100% gasoline. The matched vehicle was tested on 100% gasoline.

Bi-fuel vehicles were also paired with matching gasoline vehicles. The bi-fuel AFV was tested once on gasoline and once on the designated alternative fuel (CNG or liquefied petroleum gas, or LPG). The gasoline model was tested on gasoline.

Disclaimer: It is important to note that the results obtained are from one vehicle or one pair of vehicles (alternative fuel and gasoline version) for each model. The data cited here, although real results from testing production vehicles, may not be replicated for all like vehicle models. The results presented are intended to give an indication of the typical performance that might be expected from each vehicle tested.

Test Fuels

Alternative fuels used include E85 (85% ethanol, 15% gasoline), CNG, and LPG. Commercially available fuel (gasoline, E85, CNG, and LPG) was used to perform the mileage accumulation and the performance testing for both the gasoline vehicle and the alternative fuel candidate vehicle. If the candidate AFV was a flexible- or bi-fuel vehicle, it was operated on alternative fuel during mileage accumulation. Reference Fuel-A (RF-A), or industry average gasoline (defined under the Auto/Oil Air Quality Research Improvement Program*), was used for the gasoline emissions tests. Alcohol fuels used for emissions testing were blended using the same RFA gasoline.

Locally available winter grade gasoline (high volatility) was used for cold-start testing on both the control vehicle and the candidate vehicle. Sufficient quantities of fuel were retained for use in case vehicles are acquired and tested in warmer months. E70 (70% ethanol, balance gasoline) was used for the cold-start testing of the flexible-fuel vehicle in the ethanol configuration. Manufacturers recommend adjusting the E85 by adding high-volatility primers to achieve E70 for winter-temperature work.

Vehicle Acquisition and Pre-Test Mileage Accumulation

Test vehicles with no more than 2,500 miles were acquired. Prior to testing, miles were accumulated on each test vehicle, as needed, to 5,000 miles. The test lab used an established mileage accumulation route that comprised a mixture of highway and city driving conducted on public roads at posted speeds. This resulted in a mixture of approximately 70% highway and 30% city driving. Vehicle safety inspections were completed prior to each driving shift to ensure that the vehicles were operating properly.

General Test Preparations

- Engine oil and filters were changed according to the manufacturer's recommended practices for each vehicle.
- The wheel alignment of both vehicles was measured and adjusted.
- Fifth wheel brackets were fabricated and installed.
- The vehicles were fueled to capacity and the unloaded vehicle weights were measured and recorded.
- The engine controllers were queried for the presence of diagnostic trouble codes.

Fuel Change Procedure for Performance and Cold-Start Tests

The candidate vehicle required changes of its fuel specification during the course of performance and cold-start testing. Additionally, the emissions test fuel was changed out of both vehicles before performance and cold start tests were conducted. The procedure outlined below was used to verify that the vehicles' engine controllers had fully adapted

to the changes in fuel:

1. The outgoing fuel was drained from the fuel tank until the engine would not start.
2. Three gallons of the subject fuel were added to the tank
3. The vehicle was operated for 10 miles at a combination of engine speeds and manifold pressures such that all long-term fuel control adaptive memory cells were accessed and allowed to update as indicated by a scan tool. (A scan tool is a device that interfaces with a vehicle's on-board diagnostic system to display a variety of information from the vehicle drivetrain and subsystems.)
4. The subject fuel was drained from the fuel tank until the engine would not start.
5. Five or more gallons of the subject fuel were added to the tank.
6. For FFVs, technicians confirmed that the flexible-fuel sensor recognized the change in the alcohol content of the fuel, as indicated by a scan tool.
7. The vehicle was operated at a combination of engine speeds and manifold pressures such that all long-term, fuel-control, adaptive-memory cells were accessed and allowed to update and stabilize, as indicated by a scan tool.

Please note that this fuel change procedure is separate and distinct from the emissions test procedure. The emissions test fuel change procedure is described in *Chassis Dynamometer Emissions Testing*.

General Test Conditions

General ambient condition requirements for outdoor tests were:

- Ambient temperatures in the range of 32 to 90 degrees F.
- Dry roadway surfaces (except for wet braking tests and some low-speed driveability and handling evaluations).

Wind speed restrictions are noted in the individual tests.

* Burns, V., et al. "Description of Auto/Oil Air Quality Improvement Research Program," SAE Paper No. 912320, Warrendale, Penn., Society of Automotive Engineers, 1992.

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